§5. Observation of Plasma Hole in a Rotating Plasma, I: Structure of Density and Flow Field

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Large-scale structure formation is well known in various fluids such as geostrophic fluids, planetary atmospheric fluids, and guiding center plasmas. Formation of self-organized structure in magnetized plasmas has been a topic of basic plasma research, and many theoretical and computational studies have been performed. Recently, coherent structures have been observed in laboratory plasmas, and many of them exhibit various types of vortex motions. In order to investigate the contribution of plasma flow to the plasma structure, we have developed the method of plasma flow measurement using a directional Langmuir probe under magnetized conditions[1], and observed a variety of large-scale flow structures in an ECR plasma.

We have observed a cylindrical density hole (referred to as *plasma hole*) in a rotating magnetized plasma[2]. The perspective image of the plasma hole taken by a CCD camera located at the end of the chamber is shown in Fig. 1, in which the dark region at the center is the plasma hole. The plasma hole remains stationary as long as the plasma is sustained. Typical parameters of the present experiment are as follows; electron temperature 20-25 eV, maximum density < 1×10^{12} cm^{-3}, magnetic field ~1 kG, microwave power ~10 kW, and operation pressure 7×10^{-4} Torr (helium gas). The density profile of plasma hole measured by a Langmuir probe is shown in Fig. 2. The density in the core region is much lower than the ambient plasma, and is sharply bounded by the density peak located at the edge of the hole, which is 10 times higher than in the hole region.

The plasma flow velocity associated with the plasma hole has been measured using a directional Langmuir probe. The velocity is determined by the following equation;

$$\frac{V\cos(\theta-\theta_d)}{C_s}=2\frac{I_s(\theta+\pi)-I_s(\theta)}{I_s(\theta+\pi)+I_s(\theta)},$$

where C_s is ion sound speed, I_s the probe currents, respectively. The two-dimensional vector field of plasma flow velocity perpendicular to the magnetic field is shown in Fig. 3. The plasma rotates azimuthally in the direction of E×B drift and flows inward in radial direction. Therefore the plasma hole is found to be a sinking monopole swirl.

One of the remarkable characteristics of the plasma hole is the existence of density discontinuity; the scale length is extremely short and is several ion Larmor radii. Furthermore, in this discontinuous layer, the flow velocity reaches its maximum, exceeding ion sound speed. These results imply the formation of stationary shock structure in a rotating magnetized plasma.

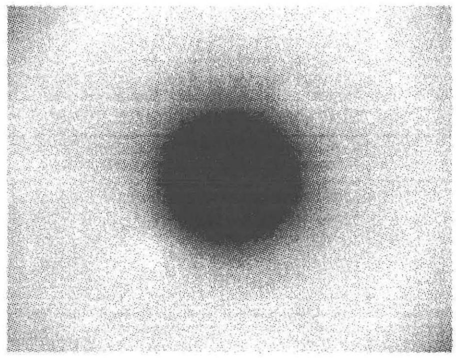

Fig. 1. CCD image of plasma hole from the chamber end.

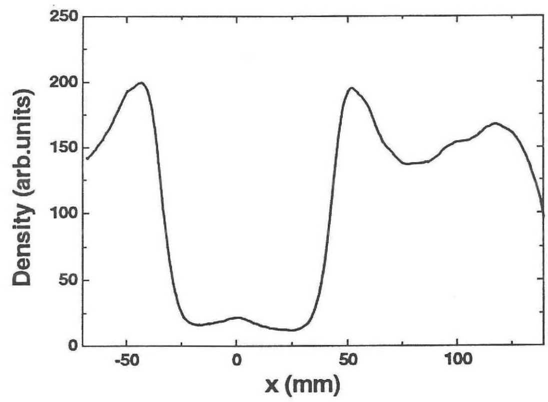

Fig. 2. The radial density profile of the plasma hole.

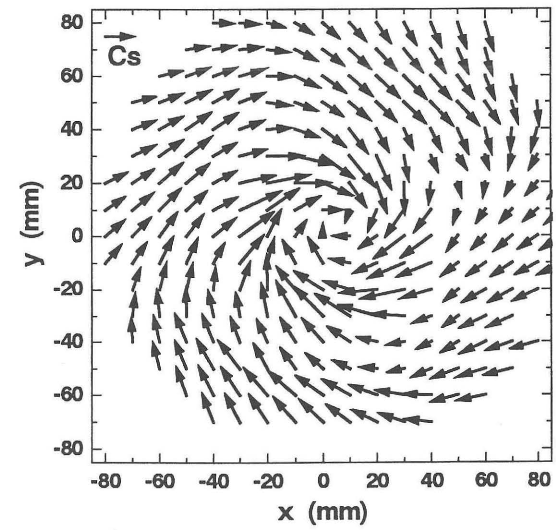

Fig. 3. Two-dimensional velocity field of plasma flow.

References

1) K. Nagaoka *et al*, J. Phys. Soc. Jpn. **70**, (2001) 131.
2) K. Nagaoka *et al*, *Proceedings of 2000 ICPP*, Vol. 1, p. 304.